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Giant magnetoresistance in quantum magnetic contacts

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Abstract

We present calculations of quantized conductance and magnetoresistance in nanosize point contacts between two ferromagnetic metals. When conductance is open for only one conduction electron spin-projection, the magnitude of magnetoresistance is limited by the rate of conduction electron spin-reversal processes. In the case when both spin-channels contribute to the conductance we analyze the influence of the point contact cross-section asymmetry on the giant megnetoresistance. Recent experiments on magnetoresistance of magnetic point contacts are discussed in the framework of the developed theory.

Keywords: Magnetic point contacts; Giant magnetoresistance; Conductance quantization

1. Introduction

Since experiments with two-dimensional electron gas in a semiconductor [1,2] it is demonstrated that electric conduction is quantized, and elementary conductance quantum is equal to $2e^2/h$. When measured on tiny contacts of nonmagnetic semiconductors and metals, the conductance quantization is limited to low temperatures by thermal fluctuations, and the factor 2 is attributed to the two-fold spin degeneracy of conduction electron states. Recently, sharp conductance quantization steps have been observed in nanosize point contacts of ferromagnetic metals at room temperature [3–6]. It was possible because phonon and magnon assisted relaxation processes are quenched due to a large, ~ 1 eV, exchange splitting of the conduction band. In addition, Oshima and Miyano [4] found an indication of the odd-valued number N of open conductance channels ($\sigma = N(e^2/h)$) in nickel point contacts from room temperature up to 770 K. Ono et al. [6] presented an evidence of switching from $2e^2/h$ conductance quantum to e^2/h quantum at room temperature in the nickel nanocontacts of another morphology. Obviously, the change of conductance quantum from $2e^2/h$ to e^2/h is a result of lifting-off the spin degeneracy of the conduction band. Recent calculations [7,8] confirmed the e^2/h conductance quantization in ferromagnetic metals, which is due to non-synchronous opening of "up" and "down" spin-channels in the point contact conduction.

A new pulse to studies of electric transport in ferromagnets has been given by the observation of giant magnetoresistance (GMR) in nanosize magnetic contacts by García et al. [9–11]. Magnetoresistance magnitudes of 280% for Ni–Ni [9] and 200% for Co–Co [10] nanosize contacts were obtained at room temperature. Somewhat smaller ($\sim 30\%$), but very large for a single interface, magnetoresistance was observed in Fe–Fe point contacts [11]. In these experiments there is a huge spread in the measured values of magnetoresistance, drawn as a function of conductance at ferromagnetic alignment of magnetizations in contacting ferromagnetic domains (F-conductance). The spread of MR points for Ni–Ni and Co–Co contacts is extremely large at F-conductance lying in the range of 2–8 elementary conductances e^2/h. The above-mentioned observations of conductance quantization steps in point junctions of ferromagnetic metals at room temperature give anticipation that conduction quantization is responsible for the giant magnitude and the giant fluctuations of magnetoresistance in tiny magnetic contacts.

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